

Natural Antifungal Botanicals in Polyherbal Shampoo Formulations for Dandruff Control: A Narrative Review

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ABSTRACT

Dandruff is a prevalent scalp disorder worldwide, affecting approximately half of the adult population. Although it is not medically severe, it results in visible flaking, persistent itching, and social discomfort. The condition is primarily linked to the overgrowth of *Malassezia* species, an imbalance in scalp oil, and individual sensitivity. Conventional treatments typically involve the use of chemical antifungal shampoos, such as ketoconazole, selenium sulfide, or zinc pyrithione. While these agents are effective, they may cause scalp irritation, dryness, and resistance issues with prolonged use.

The increasing fascination with natural and herbal remedies that are safe, environmentally friendly, and aesthetically appealing has resulted in a notable rise in consumer interest. Among the numerous plants explored for their anti-dandruff properties, Shikakai (*Acacia concinna*), Reetha (*Sapindus mukorossi*), Neem (*Azadirachta indica*), Fenugreek (*Trigonella foenum-graecum*), Aloe Vera (*Aloe barbadensis miller*), Tea Tree Oil (*Melaleuca alternifolia*), and Camphor (*Cinnamomum camphora*) are particularly

noteworthy. These ingredients possess unique phytochemical profiles and therapeutic effects: Neem and Tea Tree Oil have antifungal capabilities against *Malassezia*; Fenugreek offers scalp conditioning and anti-inflammatory advantages; Aloe Vera calms, moisturizes, and helps restore the skin's barrier function; Camphor relieves itching and provides a cooling effect; Shikakai acts as a natural surfactant, while Reetha serves as a natural cleanser and foaming agent.

In a polyherbal shampoo, these ingredients may collaborate to reduce fungal proliferation, ease symptoms, and improve scalp health. However, challenges remain concerning formulation stability, the standardization of herbal extracts, safety concerns, and the need for rigorous clinical trials. This review provides a narrative synthesis of the current evidence on these five natural agents, their antifungal properties, their potential synergistic effects in polyherbal formulations, and the future directions for research and product development.

Keywords: Dandruff, *Malassezia*, Polyherbal Shampoo, Herbal Cosmeceuticals, Antifungal Agents, Neem, Tea Tree Oil

1. INTRODUCTION

1.1 Background and Global Burden

Dandruff, known in scientific terms as *Pityriasis capitis*, is a chronic scalp condition characterized by visible flakes, itching, and irritation (1). It affects people worldwide, regardless of ethnicity or climate, with the highest prevalence among teenagers and young adults (2). Studies show that around 40–50% of individuals experience dandruff at some point after puberty, underscoring its

importance as a dermatological concern (3). Although dandruff does not cause physical disability or systemic illness, it significantly affects mental and social well-being. Individuals often feel embarrassed, suffer from reduced self-esteem, and encounter social anxiety due to the visible flakes on their clothing and persistent itching (4). In some cases, severe dandruff can progress to seborrheic dermatitis, a more inflammatory skin condition (5).

1.2 Pathophysiology

The development of dandruff is complex and involves three interconnected factors:

1. Following puberty, the sebaceous glands located in the scalp become more active, generating sebum that is rich in triglycerides, which acts as a medium for microbial growth (6).
2. Microbial colonization: Yeasts belonging to the genus *Malassezia*, specifically *M. globosa* and *M. restricta*, metabolize sebum and subsequently release free fatty acids, such as oleic acid. These acids irritate the scalp, disrupt the epidermal barrier, and expedite the turnover of skin cells (7,8).
3. Host susceptibility: Not everyone with an overgrowth of *Malassezia* develops dandruff. The severity of symptoms is influenced by individual factors such as scalp sensitivity, immune responses, and barrier integrity (9).

This reaction results in itching, redness, and the accumulation of keratinocytes, which appear as flakes.

1.3 Conventional Treatments and Limitations

Contemporary anti-dandruff treatments predominantly utilize shampoos formulated with chemical antifungal or keratolytic agents. These formulations commonly include:

- **Azoles(ketoconazole, climbazole):** Strong antifungal action but may cause dryness or resistance (10,11).
- **Zinc pyrithione:** Broad antimicrobial effects but sometimes associated with scalp irritation (12).
- **Selenium sulfide:** Effective but may leave an unpleasant odor and discoloration (13).
- **Coal tar:** Reduces cell turnover but is cosmetically unappealing (14).

Although these shampoos offer relief from symptoms, their limitations hinder long-term use. Issues such as scalp dryness, changes in hair texture, and the risk of developing microbial resistance are concerning (15,16).

1.4 Shift Toward Herbal Solutions

In recent decades, there has been a growing consumer interest in natural and herbal cosmetics (7,17). The global herbal hair care market is rapidly expanding, fueled by perceptions of safety, sustainability, and additional cosmetic benefits. Herbal ingredients are prized not only for their therapeutic properties but also for their ability to condition hair, soothe irritation, and offer a pleasant sensory experience.

Polyherbal formulations, which are shampoos that incorporate multiple herbal extracts, hold significant promise. By simultaneously addressing the fungal cause, scalp inflammation, itching, and hair conditioning, these polyherbal shampoos offer a more comprehensive approach compared to single-agent products (18).

1.5 Rationale for This Review

Among the diverse array of medicinal plants utilized for hair and scalp care, Neem, Fenugreek, Aloe Vera, Tea Tree Oil, and Camphor are particularly noteworthy for their combined antifungal, anti-inflammatory, soothing, and conditioning properties (8–13). Each of these plants boasts a history of traditional use, scientific evidence supporting their efficacy, and potential roles in controlling dandruff.

This narrative review aims to: Summarize the phytochemical profiles and antifungal mechanisms of these five agents; Compare their roles and contributions in polyherbal shampoos; Discuss formulation challenges and regulatory considerations; Identify research gaps and future opportunities for innovation.

2. LITERATURE SEARCH STRATEGY

This review was crafted using a narrative synthesis method. While it is not a systematic review, it did include a methodical and thorough literature search.

2.1 Databases

Searches were conducted in the following electronic databases: PubMed, Scopus, Web of Science, and Google Scholar.

2.2 Search Terms

The search strategy employed a combination of keywords and subject headings, including: “dandruff,” “Pityriasis capitis,” “seborrheic dermatitis”; “Malassezia,” “Malassezia globosa,” “Malassezia restricta”; “antifungal,” “herbal shampoo,” “polyherbal formulation”; “Neem,” “Azadirachta indica”; “Fenugreek,” “Trigonella foenum-graecum”; “Aloe vera,” “Aloe barbadensis miller”; “Tea Tree Oil,” “Melaleuca alternifolia”; “Camphor,” “Cinnamomum camphora”; “Reetha,” “Sapindusmukorossi”; and “Shikakai,” “Acacia concinna.” Boolean operators (AND, OR) were utilized to combine these search terms.

2.3 Inclusion and Exclusion Criteria

- **Inclusion:** In-vitro, in-vivo, and clinical studies evaluating the antifungal or scalp-health properties of these agents; review articles; relevant book chapters.
- **Exclusion:** Non-English language papers, conference abstracts without full text, and unrelated herbal studies.

2.4 Selection Process

Articles were initially screened for relevance based on their titles and abstracts. The full texts of the shortlisted papers were then reviewed to gather information on phytochemical composition, antifungal mechanisms, scalp benefits, formulation use, and clinical outcomes. Additionally, reference lists of key articles were manually searched to identify further studies.

2.5 Limitations of the Search

As this is a narrative review, the studies were not systematically evaluated for risk of bias, and no quantitative synthesis was conducted. Instead, the findings are synthesized narratively to offer a comprehensive overview of the topic.

3. PHYTOCHEMICAL PROFILES AND THERAPEUTIC MECHANISMS OF SELECTED AGENTS

The effectiveness of polyherbal formulations in therapy is due to the distinct yet complementary functions of their individual ingredients. Neem, Tea Tree Oil, Fenugreek, Aloe Vera, Shikakai, Reetha, and Camphor have been thoroughly studied for their bioactive compounds and biological

properties that are relevant to dandruff management.

3.1 Shikakai(*Acacia concinna*)

Shikakai pods are abundant in triterpenoid saponins (acacic acid glycosides), tannins, flavonoids, and contain minor quantities of alkaloids [24]. These constituents confer upon shikakai its distinctive foaming, cleansing, and antimicrobial properties.[48]

Mechanisms of anti-dandruff action:

- **Cleansing:** Saponins act as natural surfactants, removing sebum and flakes that support *Malassezia* growth [25].
- **Antimicrobial:** Tannins and flavonoids provide broad-spectrum antibacterial and antifungal activity [26].
- **Hair conditioning:** Its mild acidity maintains scalp pH and reduces hair tangling, improving overall scalp health [27].

3.2 Reetha (*Sapindusmukorossi*)

Reetha, commonly referred to as soapnut, serves as a natural cleansing agent frequently incorporated into herbal shampoos. It contains saponins, which generate foam and facilitate the removal of dirt, oil, and dandruff from the scalp. Additionally, Reetha exhibits antifungal properties against *Malassezia furfur*, the primary fungus implicated in dandruff. The principal phytochemicals contributing to the anti-dandruff efficacy of Reetha (*Sapindusmukorossi*) include hederagenin glycosides, oleanolic acid saponins, and sapindosides.[47]

Mechanism of Action

- **Natural surfactant:** Saponins reduce surface tension and remove dirt and excess oil.
- **Foaming action:** Produces foam that improves cleansing.
- **Antifungal action:** Inhibits growth of *Malassezia furfur*.

- **Sebum control:** Removes excess scalp oil, reducing dandruff formation.

Overall, Reetha acts as a natural cleanser and antifungal agent, making it effective in polyherbal anti-dandruff shampoos.

3.3 Neem (*Azadirachta indica*)

In Ayurveda, neem is frequently referred to as a "village pharmacy" because of its extensive therapeutic capabilities (19). The plant's leaves, bark, and seeds are abundant in triterpenoids, flavonoids, tannins, and glycosides. Notably, azadirachtin, Nimbolide, and nimbin are the most bioactive components, known for their antimicrobial properties (20).

Antifungal Mechanism:Neem extracts show strong effectiveness against dermatophytes and yeasts, such as *Malassezia* species (21). This effect is achieved by disrupting fungal cell walls and altering membrane permeability, which results in the leakage of cytoplasmic contents and ultimately leads to the death of the fungi (22). Methanolic leaf extracts have been found to create inhibition zones in *M. furfur* tests that are similar to those produced by ketoconazole (23).

Neem's phytochemicals interfere with fungal cell membranes, block the production of ergosterol, and decrease inflammatory cytokines. Additionally, its antioxidant capabilities help alleviate oxidative stress, which is increasingly associated with scalp barrier issues.

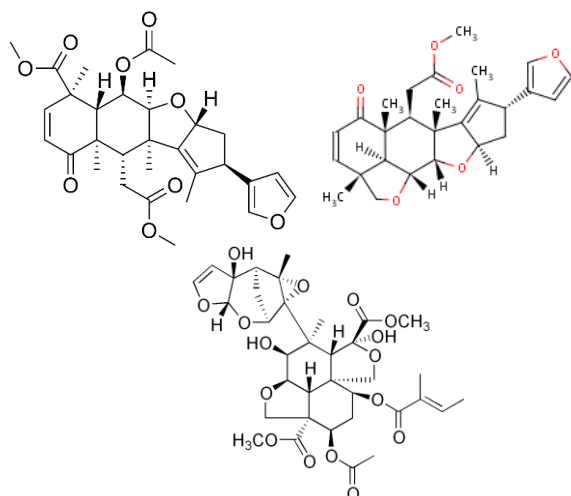


Fig 1 – Chemical Structure of Azadirachtin, Nimbolide, Nimbin (46)

Ancillary Benefits:Neem possesses anti-inflammatory and antibacterial properties that alleviate scalp irritation and help prevent secondary infections (24). Furthermore, it acts as a natural antioxidant, safeguarding scalp cells from oxidative stress, which can exacerbate dandruff (25).

3.4 Tea Tree Oil (*Melaleuca alternifolia*)

Tea Tree Oil (TTO) is an essential oil derived from the Australian plant known as *Melaleuca alternifolia*. It comprises more than 100 components, with terpinen-4-ol being the primary active ingredient, followed by γ -terpinene, α -terpinene, and 1,8-cineole (26).

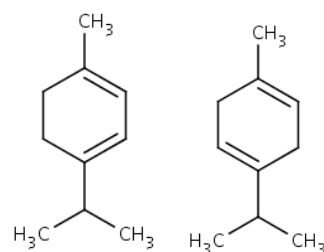


Fig 2 – Chemical Structure of γ -terpinene, α -terpinene, and 1,8-cineole (46)

Antifungal Mechanism:TTO exhibits potent antifungal effects against *Malassezia* species. Terpinen-4-ol compromises the integrity of fungal membranes, leading to increased ion leakage and respiratory inhibition (27). Its lipophilic properties enable it to penetrate sebaceous regions of the scalp, making it particularly effective for controlling dandruff.

Clinical EvidenceIn a randomized controlled trial, a 5% TTO shampoo led to a 41% reduction in dandruff severity, compared to an 11% reduction with a placebo after four weeks (28). This robust evidence establishes TTO as one of the most well-supported natural antifungal treatments for dandruff.

Additional Benefits:TTO also has antibacterial, anti-inflammatory, and mild pain-relieving effects, which contribute to maintaining scalp health (29).

3.5 Fenugreek (*Trigonella foenum-graecum*)

Fenugreek seeds are valued in both culinary and medicinal traditions. They are rich in steroidal saponins (diosgenin, yamogenin), alkaloids (trigonelline), flavonoids, and mucilaginous fibers (30).

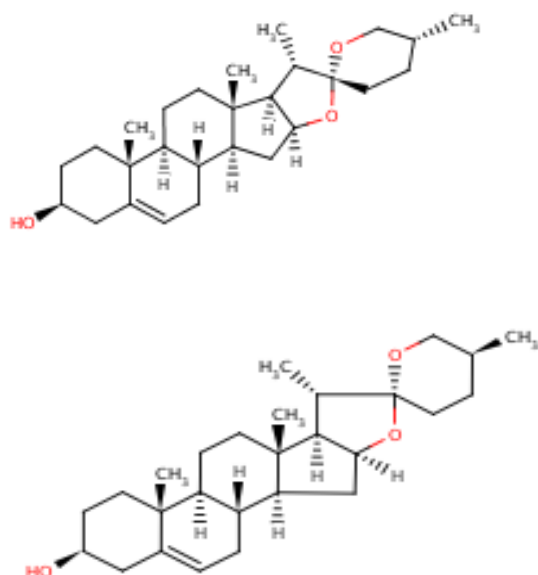


Fig 3 – Chemical Structure of diosgenin, yamogenin and trigonelline (46).

Antifungal Mechanism:Saponins function as natural surfactants that interact with sterols in fungal membranes, forming pores and compromising membrane integrity (31). While its antifungal properties are less potent than those of Neem and TTO, Fenugreek still plays a significant role in enhancing the overall effect of polyherbal formulations.

Ancillary Benefits:The mucilage in fenugreek offers hair-conditioning benefits by coating the hair shaft, resulting in smoother hair and less breakage. Its flavonoids and antioxidants help reduce inflammation and oxidative stress on the scalp (32). Additionally, the proteins and nicotinic acid in fenugreek are linked to enhanced hair strength and growth, making it a valuable ingredient in hair care formulations (33).

3.6 Aloe Vera (*Aloe barbadensis miller*)

Aloe Vera gel is composed of over 75 active compounds, including polysaccharides like acemannan, vitamins such as A, C, E, and B12, as well as enzymes, minerals, and anthraquinones (34).

Antifungal Mechanism:Aloe Vera exhibits mild to moderate antifungal and antibacterial properties, primarily due to the presence of anthraquinones such as aloin and emodin, as well as saponins (35). Although it is not a primary antifungal agent, it plays a role in maintaining overall microbiome balance.

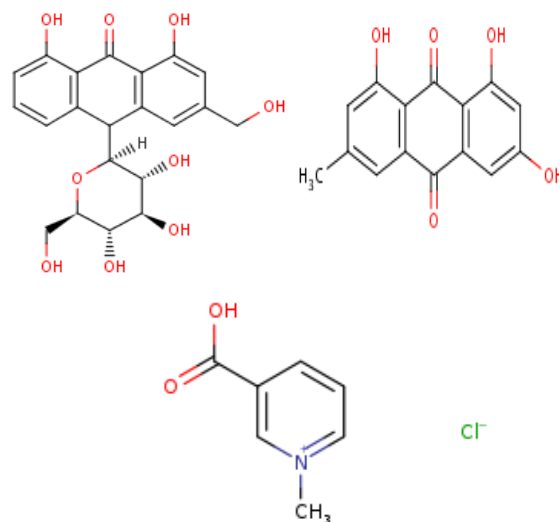


Fig 4 – Chemical Structure of aloin and emodin (46).

Ancillary Benefits:The polysaccharides in it hydrate the scalp, restoring the barrier function compromised by dandruff. Bradykinase enzymes help reduce inflammation, while proteolytic enzymes digest dead keratinocytes, gently exfoliating flakes (36). Clinical trials have shown that Aloe-based emulsions improve symptoms of seborrheic dermatitis (37).

Additional Role:Aloe not only speeds up wound healing but also reduces redness, making it essential for soothing irritated scalp conditions (38).

3.7 Camphor (*Cinnamomum camphora*)

Camphor, a terpenoid derived from the wood of the camphor tree, has been utilized in traditional medicine for its cooling and pain-relieving properties for a long time.

Antifungal Mechanism:Camphor demonstrates antifungal properties by disrupting the lipids in fungal membranes and inhibiting enzymatic

processes (39). It has been proven to inhibit the growth of yeast and dermatophytes in vitro.

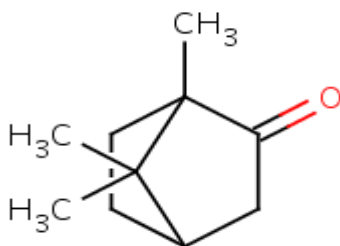


Fig. 5 - Chemical Structure of Camphor (46).

Ancillary Benefits: Camphor primarily functions as an antipruritic agent by activating transient receptor potential (TRP) channels, which produce a cooling sensation that alleviates itching (40). This is especially beneficial for dandruff, where the itch-scratch cycle exacerbates scalp inflammation. Additionally, its anti-inflammatory properties help reduce redness and irritation (41).

4. POLYHERBAL SYNERGY AND COMPARATIVE ROLES

The core principle of polyherbalism is synergy, where the combined therapeutic effect of multiple agents surpasses the sum of their individual effects (42). This is particularly beneficial for dandruff, as the condition involves a multifactorial pathogenesis that includes microbial colonization, disruption of the scalp barrier, inflammation, itching, and dryness (1,6).

In a polyherbal anti-dandruff shampoo:

- **Neem and Tea Tree Oil** act as primary antifungal agents against *Malassezia* species (8,27).
- **Fenugreek** supports antifungal action through its saponins and adds hair-conditioning properties (30,31).
- **Aloe Vera** soothes inflammation, hydrates the scalp, and helps exfoliate dead cells (34,36).
- **Camphor** provides immediate relief from itching, improving user comfort (40).
- **Reetha**, acts as natural cleansing agent
- **Shikakai** acts as foaming agent

This functional differentiation allows for the simultaneous targeting of fungal overgrowth, inflammatory symptoms, and the cosmetic aspects of dandruff. This synergy reduces fungal load, soothes inflammation, alleviates itching, and improves the feel of hair, resulting in greater compliance and consumer acceptance (18,28,37).

5. FORMULATION, STABILITY, AND REGULATORY CHALLENGES

Although herbal agents hold promise, integrating them into stable, effective, and consumer-friendly shampoo formulations presents a complex challenge.

5.1 Standardization of Herbal Extracts

- **Challenge:** The chemical composition of plants can vary due to factors such as soil, climate, harvest timing, and extraction methods. For instance, neem leaves harvested in one season might contain higher levels of nimbin compared to another batch, leading to inconsistent efficacy (7,42).
- **Solution:** Utilization of standardized extracts with specified active marker compounds, such as terpinen-4-ol at concentrations of 30% or more in Tea Tree Oil (11,39,28)

5.2 Stability of Phytochemicals

- **Challenge:** Essential oils, such as Tea Tree and Camphor, are volatile and degrade when exposed to light and heat, while Aloe polysaccharides break down in aqueous environments (39,41).
- **Solution:** Encapsulation techniques, such as liposomes and nanoemulsions, along with pH control and the use of amber-colored bottles, help prevent photodegradation (39,41).

5.3 Interaction with Shampoo Base

- **Challenge:** Surfactants such as sodium lauryl sulfate (SLS) can denature plant compounds, while the presence of ethanol or glycerin influences solubility (29,30,34,37,44).

- **Solution:** Use milder surfactants such as cocamidopropyl betaine and sodium coco-sulfate, and optimize solvent systems (29,30,34,37,44).

5.4 Sensory Properties and Consumer Acceptance

- **Challenge:** The strong medicinal scent of Neem and Tea Tree Oil might decrease consumer acceptance (22,25,27,28).
- **Solution:** Combine with aromatic oils such as lavender and rosemary, or employ natural fragrance masking agents (35,36).

5.5 Safety and Dosage Optimization

- **Challenge:** High concentrations of Tea Tree Oil or Camphor can lead to dermatitis (28,43,44). **Solution:** Maintain concentrations within safe cosmetic limits (e.g., $\leq 5\%$ TTO, $\leq 3\%$ Camphor) and conduct patch tests prior to commercial launch (20,38).

5.6 Regulatory Pathways

In India, herbal shampoos are typically regulated as either Ayurvedic/Unani/Siddha (ASU) drugs or cosmetics, depending on their claims (39). In the USA, anti-dandruff shampoos with therapeutic claims are classified as OTC drugs, requiring FDA compliance. Herbal shampoos marketed as cosmetics cannot claim to "cure/treat dandruff" but may state they "help control flaking" (40). In the EU, herbal shampoos are governed by the Cosmetic Regulation (EC No 1223/2009), which mandates safety dossiers and labeling transparency (41).

6. RESEARCH GAPS AND FUTURE DIRECTIONS

While there is promising evidence, substantial gaps persist in the realm of herbal anti-dandruff therapies.

6.1 Lack of High-Quality Clinical Trials

Most of the evidence supporting Neem, Aloe, and Fenugreek is derived from laboratory studies or small clinical trials. There is an urgent need for

large-scale, randomized, double-blind trials to compare polyherbal shampoos with standard chemical shampoos, such as ketoconazole (15,28).

6.2 Synergy Validation

Synergy is often assumed rather than demonstrated (42). Proper factorial study designs could compare: Neem alone, Tea Tree Oil alone, and their combination. Additionally, the full polyherbal formula could be compared against its individual components.

6.3 Mechanistic Studies

Advanced techniques include: Metabolomics, which identifies how herbal extracts alter scalp metabolites; Transcriptomics, which examines gene expression changes in scalp tissue following treatment; and Microbiome sequencing, which tracks the impact of herbal shampoos on scalp microbial balance.

6.4 Long-Term Safety and Resistance

Herbal agents are thought to lower the risk of resistance; however, long-term studies are limited (44,53). The safety of chronic use, particularly concerning Camphor and essential oils, needs to be established.

6.5 Innovative Formulation Technologies

Nanoemulsions enhance the solubility and stability of essential oils. Hydrogel carriers ensure prolonged contact with the scalp. Biopolymer coatings regulate the release of active ingredients during shampooing.

6.6 Consumer-Centric Research

Given that dandruff is also a cosmetic issue, consumer satisfaction studies are essential. Future research should investigate: the acceptability of texture, fragrance, and lather; the smoothness and shine of hair post-use; and the willingness to transition from chemical shampoos to herbal alternatives.

6.7 Role of Artificial Intelligence in Herbal Formulation

AI-based tools can forecast the most effective herbal combinations, simulate their interactions, and assess consumer feedback to create more efficient polyherbal shampoos. This represents a

burgeoning field in herbal product development (54).

7. CONCLUSION

The increasing prevalence of dandruff and the limitations of conventional chemical treatments have created a strong demand for safe, effective, and consumer-friendly alternatives. Polyherbal shampoos combining Neem, Tea Tree Oil, Fenugreek, Aloe Vera, and Camphor present a rational, holistic approach.

- **Neem and Tea Tree Oil** form the antifungal backbone, targeting *Malassezia* growth directly.
- **Fenugreek** contributes supportive antifungal action while improving hair quality and scalp comfort.
- **Shikakai** – acts as a natural cleansing agent to extract the dirt
- **Reetha** – acts as a foaming agent to remove dirt
- **Aloe Vera** restores hydration, barrier integrity, and reduces inflammation.
- **Camphor** provides rapid itch relief and enhances consumer acceptability with its cooling effect.

Together, these agents tackle the root cause of dandruff and its related symptoms. Their complementary functions create a therapeutic synergy that is challenging to achieve with formulations containing only a single ingredient. Nonetheless, significant gaps persist. The standardization of extracts, the stability of phytochemicals, formulation optimization, and regulatory compliance remain pressing challenges. Most importantly, there is a notable absence of robust, large-scale clinical trials to confirm the efficacy of polyherbal shampoos compared to standard chemical treatments. Future research should also prioritize advanced delivery systems, safety assessments for long-term use, and studies on consumer acceptability. If these challenges are met with scientific rigor, polyherbal shampoos based on Neem, Fenugreek, Aloe Vera, Tea Tree Oil, Reetha, Shikakai, and Camphor could become the next generation of natural anti-dandruff

therapies—offering efficacy, safety, and cosmetic appeal in a single formulation.

8. LIST OF ABBREVIATIONS

- A. indica** – *Azadirachta indica* (Neem)
- AI** – Artificial Intelligence
- AV** – Aloe Vera (*Aloe barbadensis miller*)
- AYUSH** – Ayurveda, Yoga, Unani, Siddha, and Homeopathy (India regulatory body)
- C. camphora** – *Cinnamomum camphora* (Camphor)
- CADD** – Computer-Aided Drug Design
- CAPB** – Cocamidopropyl Betaine
- CFU** – Colony Forming Unit
- CPNP** – Cosmetic Products Notification Portal (European Union)
- DL** – Deep Learning
- EMA** – European Medicines Agency
- EU** – European Union
- FDA** – Food and Drug Administration (United States)
- GMP** – Good Manufacturing Practice
- HPLC** – High Performance Liquid Chromatography
- HPMC** – Hydroxypropyl Methylcellulose
- LNPs** – Lipid Nanoparticles
- MeSH** – Medical Subject Headings
- MFC** – Minimum Fungicidal Concentration
- MIC** – Minimum Inhibitory Concentration
- ML** – Machine Learning
- NPs** – Nanoparticles
- OTC** – Over-The-Counter
- PC** – Pityriasis capitis
- PEG** – Polyethylene Glycol

- QC** – Quality Control
RCT – Randomized Controlled Trial
ROS – Reactive Oxygen Species
SD – Seborrheic Dermatitis
SLS – Sodium Lauryl Sulfate
- T. foenum-graecum** – *Trigonella foenum-graecum* (Fenugreek)
TLC – Thin Layer Chromatography
- TTO** – Tea Tree Oil (*Melaleuca alternifolia*)
TRP – Transient Receptor Potential (ion channels)
WHO – World Health Organization

Table 1: Phytochemical Constituents and Therapeutic Roles of Selected Agents

Agent	Major Phytochemicals	Antifungal Mechanism	Additional Benefits	Role in Polyherbal Shampoo
Neem	Azadirachtin, nimbin, nimbidin, flavonoids	Disrupts fungal membranes; inhibits growth of <i>Malassezia</i>	Anti-inflammatory, antibacterial	Primary antifungal driver
Tea Tree Oil	Terpinen-4-ol, cineole, terpinene	Penetrates fungal cells; disrupts membrane & respiration	Anti-inflammatory, pleasant fragrance	Primary antifungal driver
Fenugreek	Saponins, trigonelline, flavonoids, mucilage	Saponins increase fungal membrane permeability	Conditioning, anti-inflammatory	Supportive antifungal + hair conditioner
Aloe Vera	Polysaccharides, aloin, emodin, bradykinase	Mild antifungal; maintains scalp microbiome balance	Moisturizing, healing, soothing	Symptom relief & scalp recovery
Camphor	Monoterpenes (camphor, cineole, borneol)	Membrane disruption; enzyme inhibition	Cooling, antipruritic, anti-inflammatory	Rapid itch relief & sensory enhancer
Reetha	Triterpenoid saponins (sapindosides, mukorozisaponins), sugars, phenolic compounds, flavonoids	High saponin content solubilizes fungal membrane lipids and sterols, leading to membrane disruption and cell lysis. Phenolic compounds inhibit fungal enzymes and suppress biofilm formation.	Stronger cleansing and foaming, anti-inflammatory,	enhance cleansing and antifungal efficacy
Shikakai	Saponins (acacic acid glycosides), flavonoids, tannins, alkaloids, organic acids	Saponins disrupt fungal cell membranes by interacting with sterols, increasing membrane permeability and causing leakage of intracellular contents. Tannins precipitate fungal proteins and inhibit key enzymes involved in growth and spore germination. Flavonoids contribute by generating oxidative stress and interfering with membrane integrity.	Mild natural cleanser	Provides cleansing and foam, supports antifungal action against dandruff-

Table 2: Comparative Contributions of Selected Agents in Polyherbal Shampoo

Agent	Primary Role	Secondary Role(s)	Key Contribution in Polyherbal System
Neem	Potent antifungal	Anti-inflammatory, antibacterial	Core antifungal activity against Malassezia
Tea Tree Oil	Potent antifungal	Anti-inflammatory, fresh fragrance	Evidence-based antifungal driver
Fenugreek	Conditioning agent	Mild antifungal, anti-inflammatory	Enhances hair quality, scalp comfort
Aloe Vera	Soothing & healing	Mild antifungal, moisturizing	Restores barrier, hydrates scalp
Camphor	Antipruritic (itch relief)	Mild antifungal, cooling effect	Rapid symptomatic relief, user satisfaction
Shikakai	Mild natural surfactant and scalp-conditioning cleanser	Antifungal, anti-inflammatory, detangling, pH balancing	Provides gentle cleansing while preserving hair softness; supports inhibition of dandruff-causing Malassezia spp. and reduces irritation from stronger cleansing agents
Reetha	Primary natural surfactant and foam enhancer	Antifungal, sebum-removing, antimicrobial, scalp-refreshing	Delivers robust cleansing and foaming, removes excess oil and debris that favor fungal growth, and enhances the efficacy of co-formulated herbal actives through improved scalp contact

Table 3: Common Formulation Challenges and Potential Solutions

Challenge	Example(Agent Affected)	Possible Solution
Variability in phytochemicals	Neem, Fenugreek	Use standardized extracts, batch testing
Volatile compound degradation	Tea Tree Oil, Camphor	Encapsulation, amber packaging
Surfactant interaction	Aloe Vera polysaccharides	Use mild surfactants, adjust solvents
Strong odor	Neem, Tea Tree Oil	Fragrance masking or blending
Irritation at high doses	Tea Tree Oil, Camphor	Safe concentration limits, patch testing
Regulatory restrictions	All	Comply with local cosmetic/OTC rules

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